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Performance analysis in 3G/ad hoc integrated network

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Abstract: An analytical approach to evaluate the performance of the 3G/ad hoc integrated network is presented. A channel model capturing both path loss and shadowing is applied to the analysis so as to characterize power falloff vs. distance. The 3G/ad hoc integrated network scenario model is introduced briefly. Based on this model, several performances of the 3G/ad hoc integrated network in terms of outage probability, call dropping probability and new call blocking probability are evaluated. The corresponding performance formulae are deduced in accordance with the analytical models. Meanwhile, the formula of the 3G/ad hoc integrated network capacity is deduced on the basis of the formula of the outage probability. It is observed from extensive simulation and numerical analysis that the 3G/ad hoc integrated network remarkably outperforms the 3G network with regards to the network performance. This derived evaluation approach can be applied into planning and optimization of the 3G/ad hoc network.

Key words: performance analysis; 3G network; ad hoc network; integrated network

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There are various disparate wireless systems such as the 3G (third generation) network providing a wide coverage area and the ad hoc network providing short distance wireless communication. The 3G network is a central control communication network which uses fixed base stations to forward traffic for all the mobile stations. However, there is a well-known tradeoff between the capacity and the coverage area in cellular communications[1]. Compared with the 3G network, the ad hoc network is a self-organizing multihop wireless network without a fixed infrastructure[2]. So it can be used as a complement to cellular communication for establishing ubiquitous networks. The complementary strengths of the cellular network and the ad hoc network have motivated their integration.

Recently, various heterogeneous networks have attracted much attention in the research communities all around the world. In Ref. [3], the potential capacity is improved in a cellular CDMA system when ad hoc traffic relaying is used by dual-mode mobile stations. A survey of the most recent interworking mechanisms is proposed and some important open issues to achieve seamless integration are presented in Ref. [4]. In Ref. [5], a novel configuration architecture that can be deployed in the next generation of wireless networks and a predictive vertical handoff decision scheme that optimizes the handoff initiation time as well as a selection of the most optimal network are proposed. In order to avoid modifying the existing protocols in the network nodes, Lai et al. [6] proposed the application-level approach for heterogeneous network integration. Meanwhile, there are many research activities focusing on the field of the vertical handoff algorithm for integrated networks[7-10]. But these integrated networks mentioned above mainly cover the integration of cellular networks and WLAN. In the network integrating 3G and WLAN network, the access point of the WLAN network is usually fixed. However, in the network integrating 3G and ad hoc network, the mobile station can look for any mobile station as the relaying mobile station to access the network. This network is more flexible. To the best of our knowledge, there is no previous work that addresses the issue of the performance analysis for the integrated network of the 3G network and the ad hoc networks in detail.

In this paper, the network integrating 3G network and the ad hoc network is named as the C3G-A network[11]. In the conventional 3G network, the communication between the two mobile stations must be based on base stations. In such a cellular network, call blocking occurs when the base station has no available channel resource to allocate for the mobile stations and call dropping occurs when a call is terminated due to a handoff failure or a bad SIR (signal to interference ratio). These two cases are more likely to occur when the mobile station is located in a weak signal area, such as basements, tunnels, elevators and so on. However, in the C3G-A network, the mobile station can look for a relay station to access the 3G cellular network when the received SIR value of the mobile station is below the SIR threshold. Intuitively, the C3G-A network can efficiently decrease call blocking probability and call dropping probability compared with the conventional 3G cellular network.

1 C3G-A Network Scenarios Model

With the growth of data service in conventional 3G networks, the mutual interference increases and the coverage area of the cell shrinks. Consequently, call dropping probability becomes larger and the network performance becomes worse. Meanwhile, with the rapid urban growth and the increase of skyscrapers, there are more blind zones such as elevators, underground parking lots, routeways of streets, tunnels and so on. Based on this background, we propose a C3G-A network integrating 3G and ad hoc networks. Here, we consider that the mobile stations are dual-mode, having both ad hoc networks and 3G network functions. In the conventional 3G network, the communication between the two mobile stations must be based on base stations. Consequent-

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ly, they cannot implement communication if one of them is located in a blind spot of the cell. However, in the C3G-A network, the mobile station located in the blind spots of a cell can access the base station using ad hoc network relaying so as to accomplish the communication.

In the C3G-A network, there are several common scenarios, as shown in Fig. 1.

1) The two mobile stations can implement communication directly using the ad hoc network with single-hop if they are in the scope of the ad hoc network, as with the MS2 and MS9 in Fig. 1.

2) The two mobile stations can implement communication using the ad hoc network with multi-hop, as with the communication between MS1 and MS11.

3) If one of the two mobile stations is located in the blind spots of the cell, it can find a relay station to access the base station. For example, MS6 can access BS3 via MS7, and MS4 can access BS2 via MS8.

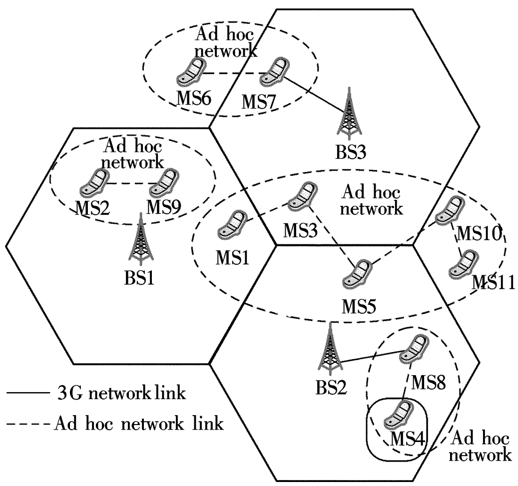

Fig. 1 C3G-A network scenarios model

2 C3G-A Network Performance Analysis

In wireless communication systems, the complexity of signal propagation makes it difficult to obtain a single model that characterizes path loss accurately across a range of different environments. Models for path loss and shadowing can be superimposed to capture power falloff vs. distance along with the random attenuation about this path loss from shadowing. For this combined model, the received power in dB is given by[12]

$$P_{\mathrm{r}}(\mathrm{dB}) = P_{\mathrm{t}}(\mathrm{dB}) + 10\log K - 10\gamma \log \frac{d}{d_0} - \psi_{\mathrm{dB}} \tag{1}$$

where P_{r} is the received power in dB; P_{t} is the transmitted power in dB; K is a unitless constant that depends on the antenna characteristics and the average channel attenuation; d_0 is the reference distance for the antenna far-field; d is the distance between the mobile station and the base station; γ is the path-loss exponent; and ψ_{dB} is a Gauss-distributed random variable with mean zero and variance $\sigma^2_{\psi_{\mathrm{dB}}}$.

2.1 Outage probability

In conventional 3G mobile communication networks, there is a targeted minimum signal to interference ratio $\mathrm{SIR}_{\min}$ below which performance becomes unacceptable.

According to the definition of the SIR, we can obtain the received SIR value at mobile station j as

$$\mathrm{SIR}(N)_j = \frac{W}{vR} \frac{P_{\mathrm{r}}^{(j)}}{\alpha \sum_{i=1, i\neq j}^{N} P_{\mathrm{r}}^{(i)} + P_{\mathrm{n}}} = \chi \frac{P_{\mathrm{r}}^{(j)}}{\alpha \sum_{i=1, i\neq j}^{N} P_{\mathrm{r}}^{(i)} + P_{\mathrm{n}}} \tag{2}$$

Here, the perfect power-control is applied to the 3G network. $P_{\mathrm{r}}^{(i)}$ is the received power from mobile station i at the base station; N is the ongoing user number in the cell; W is the chip rate; v is the average activity factor of the user; R is the bit rate of the user; χ is the gain factor; α is the non-orthogonal factor ($\alpha = 0$ for a fully orthogonal system, and $\alpha = 1$ for a fully nonorthogonal system), and P_{n} is the receiver noise power.

Eq. (2) can be rewritten in decibels as

$$\mathrm{SIR}(d_j, N)_j = P_{\mathrm{t}}^{(j)} + 10\log K - 10\gamma \log \frac{d_j}{d_0} - \psi_{\mathrm{dB}} + 10\log \chi - I_j \tag{3}$$

where $I_j = 10\log \left(\alpha \sum_{i=1, i\neq j}^{N} P_{\mathrm{t}}^{(j)} G_j + P_{\mathrm{n}} \right)$ and d_j is the distance between mobile station i and the base station.

We define $P_{\mathrm{out}}(d, N)$ to be the outage probability that the received SIR value for the user number N in the current cell at a given distance d, or $\mathrm{SIR}(d, N)$, falls below $\mathrm{SIR}_{\min}$: $P_{\mathrm{out}}(d, N) = p(\mathrm{SIR}(d, N) < \mathrm{SIR}_{\min})$, and we can obtain that

$$P_{\mathrm{out}}(d, N)_j = p(\mathrm{SIR}(d, N)_j \leqslant \mathrm{SIR}_{\min}) = 1 - Q\left(\frac{\mathrm{SIR}_{\min} - \left(P_{\mathrm{t}}^{(j)} + 10\log K - 10\gamma \log \frac{d_j}{d_0} + 10\log \chi - I_j \right)}{\sigma_{\psi_{\mathrm{dB}}}} \right) \tag{4}$$

Assume that the locations of all the users in this cell follow a uniform distribution and denote the radius as R, then

$$f(r) = \begin{cases} \frac{2r}{R^2} & 0 \leqslant r \leqslant R \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

where $f(r)$ is the probability density function of the distance between the mobile station and the base station. So the average outage probability is given by

$$\overline{P_{\mathrm{out\_3g}}(N)} = \int_0^R P_{\mathrm{out}}(l, N) \frac{2l}{R^2} \mathrm{d}l \tag{6}$$

Since the CDMA capacity is interference limited, both the communication quality of ongoing calls and the admission condition of new arriving calls for each cell depend on the time-varying SIR. In this paper we use a simple CAC (call admission control scheme). For a new call, to guarantee QoS, we deny it if the average outage probability is above 0.05 after it is allowed to access the 3G network. Traditionally, the capacity of the 3G network is determined by the outage probability, which is set as a fixed value for all the types of traffic[13]. Consequently, the network capacity C_{3g} is the maximum user number when the average outage probability is below a threshold value p, and it can be expressed as

$$C_{3g} = \arg\max_{N}(\overline{P_{out\_3g}(N)} \leqslant p) \tag{7}$$

In the C3G-A network, we assume that a mobile station MS1 fails to access the base station BS1 due to the shadow fading, as shown in Fig. 2. Consequently, MS1 will scan the area around it to find a relay mobile station to establish an ad hoc network. We denote the longest distance that the two mobile stations can establish a direct link as R_{adhoc}, and denote the distance between MS1 and BS0 as r. Meanwhile, we define the user density d_{user} as the user number per unit area. Furthermore, we denote the proportion of the ongoing users in all the users as λ. So we can obtain

$$N_{user} = (1-\lambda)\pi R_{adhoc}^2 d_{user} \tag{8}$$

$$N = \lambda \pi R^2 d_{user} \tag{9}$$

where R is the radius of the cell in the 3G network; N_{user} is the number of the available users to relay; N is the ongoing user number in the current cell. As shown in Fig. 2, we consider that MS1 can find an idle mobile station MS2 to relay and there is no failure for the communication between MS1 and MS2 in the ad hoc network. The probability that MS2 cannot successfully access BS0 is denoted as P_{out_relay}. So, it is found that

$$P_{out\_relay}(SIR_{min}, r, N) = \int_0^{R_{adhoc}}\int_0^{2\pi} P_{out}(SIR_{min}, \sqrt{a^2 + r^2 - 2ar\cos\theta}, N)\frac{2a}{R_{adhoc}^2}\frac{1}{2\pi}d\theta da \tag{10}$$

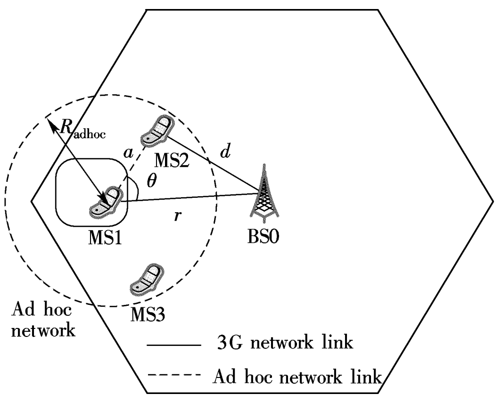

Fig. 2 C3G-A network analysis model for single cell

Because there are N_{user} users who can relay MS1 to access BS0, the probability that MS1 can successfully find an idle mobile station and access the base station is obtained as

$$P_{find\_relay\_ms} = 1 - (P_{out\_relay}(SIR_{min}, r, N))^{N_{user}} \tag{11}$$

In the C3G-A system, we redefine the outage probability as the probability that both MS1 and MS2 cannot successfully access BS0. In other words, MS1 needs to find a relaying mobile station if its received SIR value is below SIR_{min}, and we consider that MS2 can relay MS1 to access BS0, but there is also an outage probability for MS2 if MS2 has successfully accessed BS0 as a relay station. Here, MS1 should select the one with the maximum SIR value. Namely, MS1 will select the mobile station MS2 with the minimum outage probability.

$$P_{min\_out\_relay}(SIR_{min}, r, N) = \min(P_{out\_relay}(SIR_{min}, r, N, i)) \quad i = 1, 2, \ldots, N_{user} \tag{12}$$

$$P_{out\_c3g\_a}(SIR_{min}, r, N) = P_{out}(SIR_{min}, r, N)((1 - P_{find\_relay\_ms}) + P_{min\_out\_relay}(SIR_{min}, r, N)P_{find\_relay\_ms}) \tag{13}$$

In the same way, the average outage probability in the C3G-A network is

$$\overline{P_{out\_c3g\_a}(N)} = \int_0^R P_{out\_c3g\_a}(SIR_{min}, l, N)\frac{2l}{R^2}dl \tag{14}$$

Finally, we can obtain the network capacity as

$$C_{c3g\_a} = \arg\max_{N}(\overline{P_{out\_c3g\_a}(N)} \leqslant p) \tag{15}$$

2.2 Call dropping probability

Call dropping probability is the probability that a call is terminated due to a handoff failure or poor signals. The mobile station cannot maintain the communication with the base station if its received SIR value is below SIR_{min}. Consequently, in the conventional 3G network, call dropping will occur if a mobile station cannot successfully handoff to an adjacent cell when its received SIR value from the current base station is below SIR_{min}. We define the probability that a mobile station at a given distance d and the ongoing user number N in this cell fails to handoff to the adjacent cells as $P_{failtoho}(l, N, \beta)$. So we can obtain the call dropping probability,

$$\overline{P_{calldropping\_3g}(N, l)} = \int_0^{2\pi} P_{out}(SIR_{min}, l, N)P_{failtoho}(l, N, \beta)\frac{1}{2\pi}d\beta \tag{16}$$

$$\overline{P_{calldropping\_3g}(N)} = \int_0^R \overline{P_{calldropping\_3g}(N, l)}\frac{2l}{R^2}dl = \int_0^R\int_0^{2\pi} P_{out}(SIR_{min}, l, N)P_{failtoho}(l, N, \beta)\frac{2l}{R^2}\frac{1}{2\pi}d\beta dl \tag{17}$$

$$P_{failtoho}(l, N, \beta) = \prod_{i=1}^{6} P_{failtobs}(i, l, N, \beta) \tag{18}$$

$$P_{failtobs}(i, l, N, \beta) = P_{out}(SIR_{min}, \sqrt{L_{bs\_bs}^2 + l^2 - 2L_{bs\_bs}l\cos(\beta + (i-1)60)}, N) \quad i = 1, 2, \ldots, 6 \tag{19}$$

where $P_{failtobs}(i, l, N, \beta)$ is the probability that a mobile station cannot access the base station i ($i = 1, 2, \ldots, 6$); L_{bs_bs} is the distance between any two adjacent base stations. An idealized placement of the base stations is shown in Fig. 3.

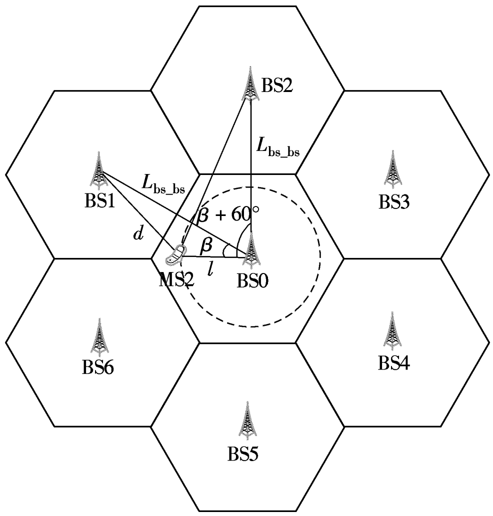

Fig. 3 Conventional 3G network analysis model

Now, we analyze the C3G-A network. Two main cases are analyzed. One is that a mobile station cannot access the base station because of the shadow fading, but it can successfully find a relaying mobile station to access the current base station, as shown in Fig. 2. The other case is that a mobile station which cannot directly access the local base station fails to find a relaying mobile station to access the current base station, but it can successfully find a relaying mobile station to access an adjacent cell, as shown in Fig. 4. In the C3G-A network, this case will occur when a mobile station cannot find a suitable relaying mobile station to access the local base station or there are not available channel resources for a new call. Apparently, the C3G-A network can decrease call dropping probability and new call blocking probability.

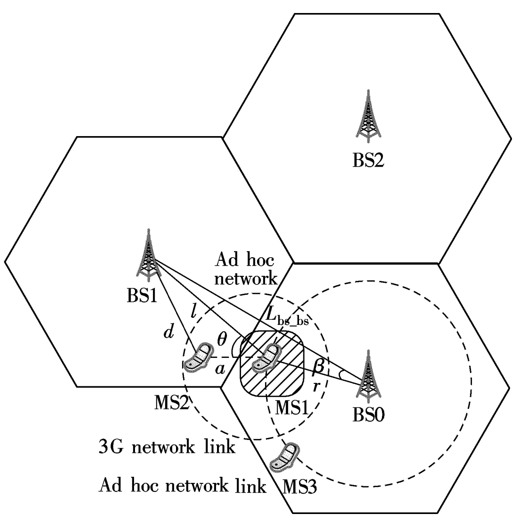

Fig. 4 C3G-A network analysis model for mutiple cells

To sum up, in the C3G-A network, call dropping will occur if the mobile station cannot successfully find a relaying mobile station to access a base station (the local base station or the adjacent base stations) or successfully handoff to an adjacent cell when its received SIR value of the current cell is below $\mathrm{SIR}_{\min}$. That is

$$\overline{P_{\text{calldropping\_c3g\_a}}(N,r)} = \int_0^{2\pi} P_{\text{out}}(\mathrm{SIR}_{\min}, r, N) P_{\text{failtoho}}(r,N,\beta) \cdot (1-P_{\text{find\_relay\_ms}})(1-P_{\text{find\_adj\_relay\_ms}}(r,N,\beta)) \frac{1}{2\pi}\mathrm{d}\beta \tag{20}$$

$$\overline{P_{\text{calldropping\_c3g\_a}}(N)} = \int_0^R \overline{P_{\text{calldropping\_c3g\_a}}(N,r)} \frac{2r}{R^2}\mathrm{d}r = \int_0^R\int_0^{2\pi} P_{\text{out}}(\mathrm{SIR}_{\min}, r, N) P_{\text{failtoho}}(r,N,\beta)(1-P_{\text{find\_relay\_ms}}) \cdot (1-P_{\text{find\_adj\_relay\_ms}}(r,N,\beta)) \frac{2r}{R^2}\frac{1}{2\pi}\mathrm{d}\beta\mathrm{d}r \tag{21}$$

$$P_{\text{find\_adj\_relay\_ms}}(r,N,\beta) = 1 - \prod_{i=1}^{6} P_{\text{failrelaytobs}}(i,r,N,\beta) \tag{22}$$

$$P_{\text{failrelaytobs}}(i,r,N,\beta) = \left(\overline{P_{\text{out}}(\mathrm{SIR}_{\min}, d(i), N)}\right)^{N_{\text{user}}} \tag{23}$$

$$\overline{P_{\text{out}}(\mathrm{SIR}_{\min}, d(i), N)} = \int_0^{R_{\text{adhoc}}}\int_0^{2\pi} P_{\text{out}} \cdot (\mathrm{SIR}_{\min}, \sqrt{l^2(i)+a^2-2l(i)a\cos\theta}, N) \frac{2a}{R_{\text{adhoc}}^2}\frac{1}{2\pi}\mathrm{d}\theta\mathrm{d}a \tag{24}$$

$$l(i) = \sqrt{L_{\text{bs\_bs}}^2 + r^2 - 2rL_{\text{bs\_bs}}\cos(\beta+(i-1)60)} \quad i=1,2,\ldots,6 \tag{25}$$

2.3 New call blocking probability

New call blocking probability is the probability that a new call is blocked. When there is no available channel resource to allocate for the new call, call blocking will occur. We denote the average new call blocking probability in the conventional 3G network as

$$P_{\text{ncb\_3g}} = E(C_{3g},\beta) = \frac{\dfrac{\beta^{C_{3g}}}{C_{3g}!}}{\sum_{k=0}^{C_{3g}} \dfrac{\beta^k}{k!}} \tag{26}$$

where λ is the average arrival rate; $\beta=\lambda T_s$, T_s is the average call duration.

Likewise, in the C3G-A system, the new call blocking probability is given by

$$P_{\text{ncb\_c3g\_a}} = E(C_{\text{c3g\_a}},\beta) = \frac{\dfrac{\beta^{C_{\text{c3g\_a}}}}{C_{\text{c3g\_a}}!}}{\sum_{k=0}^{C_{\text{c3g\_a}}} \dfrac{\beta^k}{k!}} \tag{27}$$

3 Numerical Results and Discussion

In this part, some simulation results are obtained based on the aforementioned analysis. The simulation parameters are given in Tab. 1.

Tab. 1 Simulation parameters

Parameter	Value	Parameter	Value
R/m	600	R_{adhoc}/m	100
$\mathrm{SIR}_{\min}$/dB	5.3	K	7×10^{-4}
P_T/dBm	20	α	0.1
γ	3.71	$\sigma_{\psi_{\text{dB}}}$	3.65
G	100	P_n/dBm	−105

The outage probabilities of the C3G-A network and the conventional 3G network are compared in Fig. 5. It is shown that the outage probability increases with the increase in the distance between the mobile station and the base station. This is because the longer the distance is, the bigger the signal attenuation will be. In the C3G-A network, the mobile station can find a relaying mobile station to access the base station if the mobile station fails to access the base station when its received SIR value is below SIR_{min}. Here, we take the outage probability of the C3G-A network as the probability that both the mobile station and the relay station cannot access the base station. From Fig. 5, it can be seen that the C3G-A network can obtain better performance in terms of outage probability than the conventional 3G network. Subsequently, the capacities of the C3G-A network and the conventional 3G network are compared in Fig. 6. When the targeted outage probability is set at 0.05, it is found that the capacity of the C3G-A network (248 users per cell) is greater than the capacity of the conventional network (101 users) by about 146%.

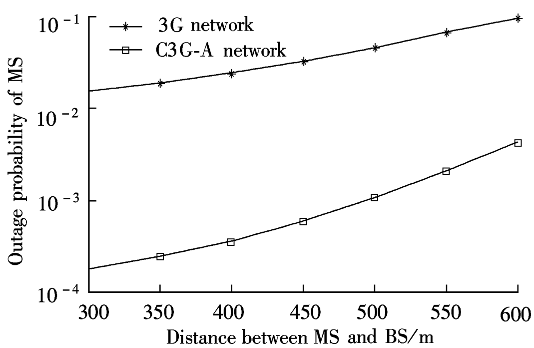

Fig. 5 Outage probability in C3G-A system compared with that in conventional 3G network (N_{cell} = 1 000, λ = 0.075)

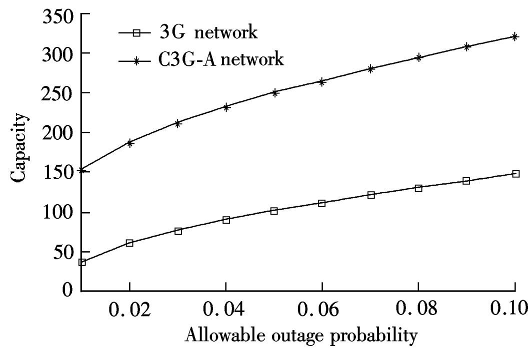

Fig. 6 Capacity of C3G-A network compared with that of conventional 3G network (N_{cell} = 1 000, λ = 0.075)

Similarly, the call dropping probabilities of the C3G-A network and the conventional 3G network are compared in Fig. 7. In the conventional 3G network, call dropping will occur when a mobile station cannot maintain the communication with the current base station or cannot successfully handoff to the adjacent base station when its received SIR value is below SIR_{min}. However, in the C3G-A network, the mobile station can find a relaying mobile station to access the current base station or an adjacent base station when its received SIR value is below the SIR threshold SIR_{min}. Therefore, the call dropping probability in the C3G-A network is greatly reduced compared with that in the conventional 3G network, as shown in Fig. 7. For example, the call dropping probability in the conventional 3G network is about 0.016 41, but the call dropping probability in the C3G-A network is only 0.000 240 2. This means that the call dropping only occurs in the C3G-A network if there are adequate available channels. At the same time, there is another case which deserves attention: in the C3G-A network, the call dropping probability at a given distance of 550 m is even less than at a given distance of 350 m. This is due to the fact that the mobile station at a distance of 550 m more likely successfully finds a relaying mobile station to access an adjacent base station than the mobile station at a distance of 350 m does.

In Fig. 8, we compare the new call blocking probability in the C3G-A network with that in the conventional 3G network. Either the allowable outage probability ε is equal to 0.05 or 0.01, it is shown that the C3G-A network outperforms the conventional 3G network with respect to the new call blocking probability.

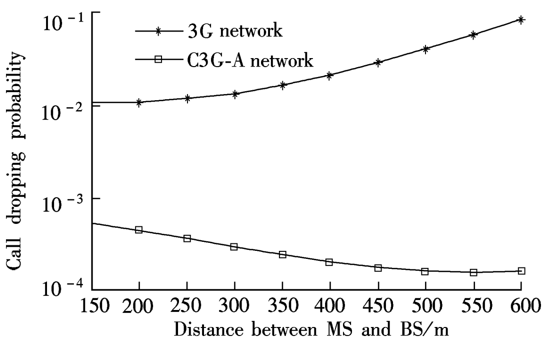

Fig. 7 Call dropping probability in C3G-A network compared with that in conventional 3G network (N_{cell} = 1 000, λ = 0.075)

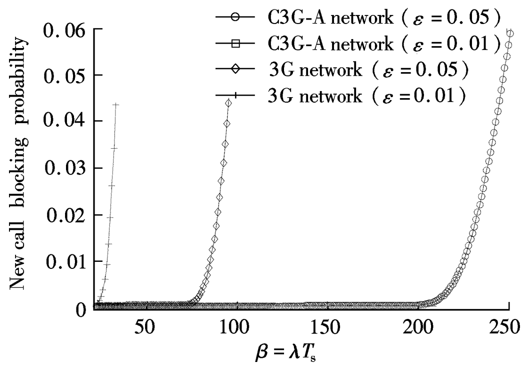

Fig. 8 New call blocking probability in C3G-A network compared with that in conventional 3G network

4 Conclusion

In this paper, a performance analytical approach for the C3G-A network which integrates the 3G network and the ad hoc network is proposed. C3G-A network performances in terms of the outage probability, the call dropping probability and the new call blocking probability are analyzed. Numerical results show that the performance of the C3G-A network with respect to these aspects outperforms the conventional 3G network. Especially, there is a very remarkable improvement in terms of the call dropping probability. The result is inspiring. It is an efficient way to improve the performance of the 3G network.

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3G/ad hoc 融合网络的性能分析

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摘要:针对3G/ad hoc 融合网络提出了一种性能分析方法. 接收功率与路径的衰减关系基于路径的自然损耗与阴影衰落. 首先,对3G/ad hoc 融合网络的应用场景模型进行了简要的介绍. 然后,基于此网络的应用场景,提出了几种性能分析方法来计算融合网络的中断概率、掉话率、新呼叫用户拥塞率等性能指标,随后推导出相应的性能公式并与传统3G 网络的上述性能进行了比较. 同时,基于融合网络的中断概率推导出融合网络的容量公式. 仿真结果表明3G/ad hoc 融合网络比传统的3G 网络在前述性能方面表现得更好,3G 网络中引入 ad hoc 能够有效地提高其系统性能. 本性能分析方法可以用于3G/ad hoc 融合网络的规划与优化.

关键词:性能分析;第三代移动网路;自组织网络;融合网络

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